United States
Coast Guard

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NAVIGATION AND VESSEL INSPECTION CIRCULAR NO. 4-93
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Subj: Subdivision and Damage Stability of Dry Cargo Vessels

1. PURPOSE. The purpose of this Circular is to promulgate International Maritime Organization (IMO) Resolution A.684(17), "Explanatory Notes to the SOLAS Regulations on Subdivision and Damage Stability of Dry Cargo Ships of Over 100 Meters (328 feet) in Length."

2. BACKGROUND.

   a. In 1985, the Maritime Safety Committee (MSC) of the IMO instructed the technical Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety (SLF) to develop a subdivision and damage stability standard based on the probabilistic analysis method. The standards that were developed are based on the research work done for the probabilistic rules for passenger ships (IMO Resolution A.265(VIII)).

   b. IMO Resolution MSC.19(58), "Regulations for the Damage Stability Requirements of Dry Cargo Ships," became effective on February 1, 1992, as an amendment to the International Convention for the Safety of Life at Sea, 1974 (SOLAS). The U.S. Coast Guard published a final rule (58 FR 17316) on April 1, 1993, which adopted this international standard into 46 CFR Part 174.

   c. The SLF Sub-Committee developed the consolidated text of the explanatory notes to the regulation subdivision and damage stability of dry cargo ships which was published as Resolution A.684(17). A

3. DISCUSSION.

   a. The probabilistic approach of the regulations takes into account the probability of various extents of damage occurring anywhere along the ship's length and the resulting flooding. At the same time it takes into account the probability that the ship will survive the damage given its stability and draft. This provides a rational means of assessing the safety of ships, where flooding is concerned, no matter what their arrangements might be. For instance, a ship may be designed with less subdivision in part of its length, provided it has additional subdivision in areas shown to have a higher probability of damage. In this respect, it frees designers and operators from unnecessarily arbitrary restrictions on arrangements.

   b. This Circular is initial guidance for the marine shipping industry, ship designers, and the U.S. Coast Guard. As experience with the probabilistic method is gained this information will be updated accordingly.

c. Any questions concerning the regulations on subdivision and damage stability should be directed to the U.S. Coast Guard's Marine Safety Center (MSC). The MSC will review all questions from the civilian marine industry concerning the new regulations on subdivision and damage stability and will consult with the U.S. Coast Guard's Marine Technical Hazardous Materials Division if further clarification is necessary.

4. IMPLEMENTATION.

a. Enclosure (1), IMO Resolution A.684(17), has been promulgated as international policy to assist interpretation of the SOLAS regulations on the subdivision and damage stability of dry cargo vessels including Ro/Ro ships of over 100 meters (328 feet) in length. These explanatory notes shall be used in conjunction with both part B-i of chapter Il-i of SOLAS 1974 and 46 CFR 174.

R. C. NORTH
ACTING CHIEF, OFFICE OF MARINE SAFETY,
SECURITY & ENVIRONMENTAL PROTECTION

Resolution A.684(17)

Adopted on 6 November 1991
(Agenda item 10)

EXPLANATORY NOTES TO THE SOLAS REGULATIONS ON SUBDIVISION AND DAMAGE STABILITY OF CARGO SHIPS OF 100 METRES IN LENGTH AND OVER

THE ASSEMBLY,

RECALLING Article 15(j) of the Convention on the International Maritime Organization concerning the functions of the Assembly in relation to regulations and guidelines concerning maritime safety,

RECALLING FURTHER that by resolution A.265(VIII) the Assembly adopted regulations on subdivision and stability of passenger ships, which may be used as an equivalent to part B "Subdivision and stability" of chapter II-1 of the 1974 SOLAS Convention,

NOTING that by resolution MSC.19(58) the Maritime Safety Committee at its fifty-eighth session adopted amendments to the 1974 SOLAS Convention to include, as part B-1 of chapter II-1, regulations for subdivision and damage stability of cargo ships which apply to cargo ships of 100 m in length and over,

NOTING FURTHER that the Maritime Safety Committee, in adopting the above amendments to the 1974 SOLAS Convention, recognized the necessity of development of appropriate explanatory notes for implementation of the regulations adopted, in order to ensure their uniform application,

HAVING CONSIDERED the recommendations made by the Maritime Safety Committee at its fifty-ninth session,

1. ADOPTS the explanatory notes to the SOLAS regulations on subdivision and damage stability of cargo ships of 100 m in length and over set out in the annex to the present resolution;

2. INVITES Governments to apply the explanatory notes when implementing the regulations for subdivision and damage stability contained in the amendments to chapter II-1 of the 1974 SOLAS Convention adopted by resolution MSC.19(58).

Annex

EXPLANATORY NOTES TO THE SOLAS REGULATIONS ON SUBDIVISION AND DAMAGE STABILITY OF CARGO SHIPS OF 100 METRES IN LENGTH AND OVER

These explanatory notes are divided into two parts. Part A describes the background to the method used while part B contains explanations and amplifications of individual regulations.

Part A

In this part of the explanatory notes, the background of the subdivision index is presented and then the calculation of the probability of damage is developed.

Finally, the development of the calculation of the probability that a damaged ship will not capsize or sink is demonstrated.

1 INTRODUCTION

The SOLAS regulations on subdivision and damage stability, as contained in part B-1 of SOLAS chapter II-1, are based on the probabilistic concept which takes the probability of survival after collision as a measure of ship's safety in the damaged condition, hereinafter referred to as the "attained subdivision index A".

This is an objective measure of ship safety and therefore there is no need to supplement this index by any deterministic requirements. These new regulations, therefore, are primarily based on the probabilistic approach, with only very few deterministic elements which are necessary to make the concept practicable.

The philosophy behind the probabilistic concept is that two different ships with the same index of subdivision are of equal safety and therefore there is no need for special treatment for specific parts of the ship. The only areas which are given special attention in these regulations are the forward and bottom regions which are dealt with by special rules concerning subdivision, provided for the cases of ramming and grounding.

In order to develop the probabilistic concept of ship subdivision, it is assumed that the ship is damaged. Since the location and size of the damage is random, it is not possible to state which part of the ship becomes flooded. However, the probability of flooding a space can be determined if the probability of occurrence of certain damages is known. The probability of flooding a space is equal to the probability of occurrence of all such damages which just open the considered space. A space is a part of the volume of the ship which is bounded by undamaged watertight structural divisions.

Next, it is assumed that a particular space is flooded. In addition to some inherent characteristics of the ship, in such a case there are various factors which influence whether the ship can survive such flooding; they include the initial draught and *GM*, the permeability of the space and the weather conditions, all of which are random at the time when the ship is damaged. Provided that the limiting combinations of the aforementioned variables and the probability of their occurrence are known, the probability that the ship will not capsize or sink, with the considered space flooded, can be determined.

The probability of survival is determined by the formula for entire probability as the sum of the products for each compartment or group of compartments of the probability that a space is flooded multiplied by the probability that the ship will not capsize or sink with the considered space flooded.

Although the ideas outlined above are very simple, their practical application in an exact manner would give rise to several difficulties. For example, for an extensive but still incomplete description of the damage, it is necessary to know its longitudinal and vertical location as well as its longitudinal, vertical and transverse extent. Apart from the difficulties in handling such a five-dimensional random variable, it is impossible to determine its probability distribution with the presently available damage statistics. Similar conditions hold for the variables and physical relationships involved in the calculation of the probability that a ship with a flooded space will not capsize or sink.

In order to make the concept practicable, extensive simplifications are necessary. Although it is not possible to calculate on such a simplified basis the exact probability of survival, it is possible to develop a useful comparative measure of the merits of the longitudinal, transverse and horizontal subdivision of the ship.

2 DETERMINATION OF THE PROBABILITY OF FLOODING OF SHIP SPACES

2.1 Consideration of longitudinal damage location and extent only

The simplest case is to consider the location and length of damage in the longitudinal direction. This would be sufficient for ships with no longitudinal and horizontal watertight structural divisions.

With the damage location *x* and damage length *y* as defined in figure 1, all possible damages can be represented by points in a triangle which is also shown in this figure.

All damages which open single compartments of length l_i are represented in figure 1 by points in triangles with the base l_i. Triangles with the base $l_i + l_j$ (where $j = i+1$) enclose points corresponding to damages opening either compartment i, or compartment j, or both of them. Correspondingly, the points in the parallelogram ij represent damages which open both the compartments i and j.

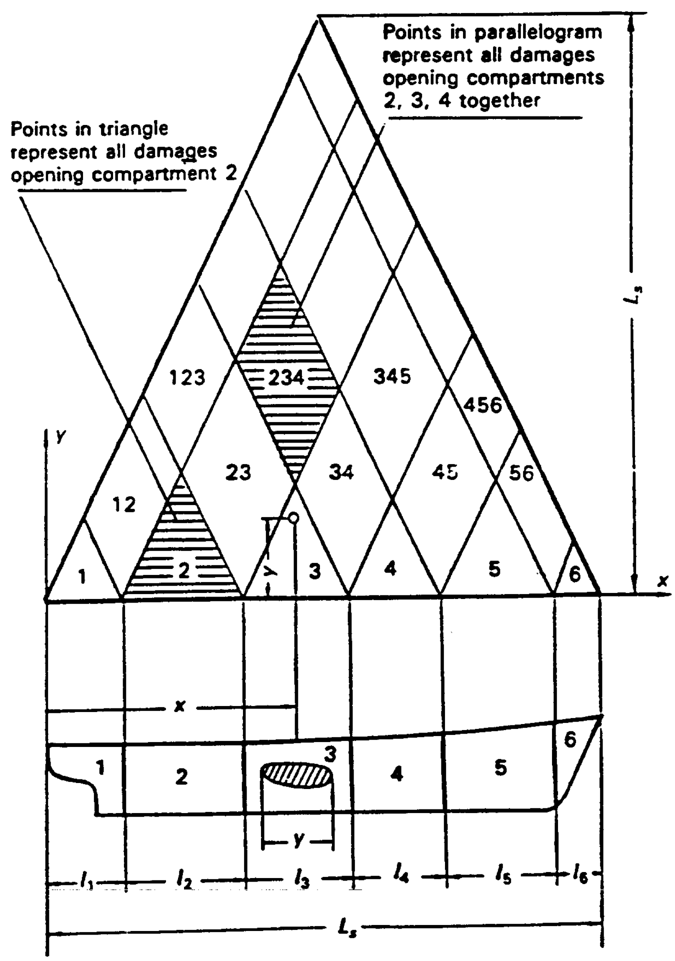

Figure 1

Damage location x and damage length y are random variables. Their distribution density $f(x,y)$ can be derived from the damage statistics. The meaning of $f(x,y)$ is as follows (see figure 2): the total volume between the x-y plane and the surface given by $f(x,y)$ equals one and represents the probability that there is damage (this has been assumed to be certain). The volume above a triangle corresponding to damage which opens a compartment represents the probability that this compartment is opened. In a similar manner for all areas in the x-y plane which correspond to the opening of compartments or group of compartments, there are volumes which represent the probability that the considered compartments or group of compartments are opened.

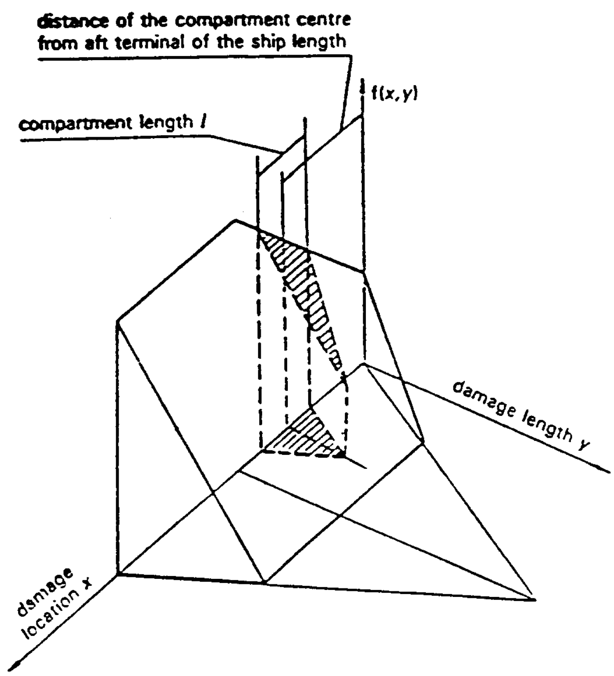

Figure 2

The probability that a compartment or a group of adjacent compartments is opened is expressed by the factor p_i as calculated according to regulation 25-5.

Consideration of damage location x and damage length y only would be fully correct in the case of ships with pure transverse subdivision. However, there are very few, if any, such ships – all normally have a double bottom, at least.

In such a case, the probability of flooding a compartment should be split up into the following three components: probability of flooding the double bottom only, probability of flooding the space above the double bottom only and probability of flooding both the space above and the double bottom itself (see figure 3). For each of these cases there may be a different probability that the ship will survive in the flooded condition. A way out of this dilemma, which may be used in applying these new regulations, is to assume that the most unfavourable vertical extent of damage (out of the three possibilities) occurs with the total probability p. Therefore the contribution to survival probability made by more favourable cases is neglected. That the concept is still meaningful for comparative purposes follows from the fact that the error made by neglecting favourable effects of horizontal subdivision is not great and the more important influence of longitudinal damage location and extension is fully covered.

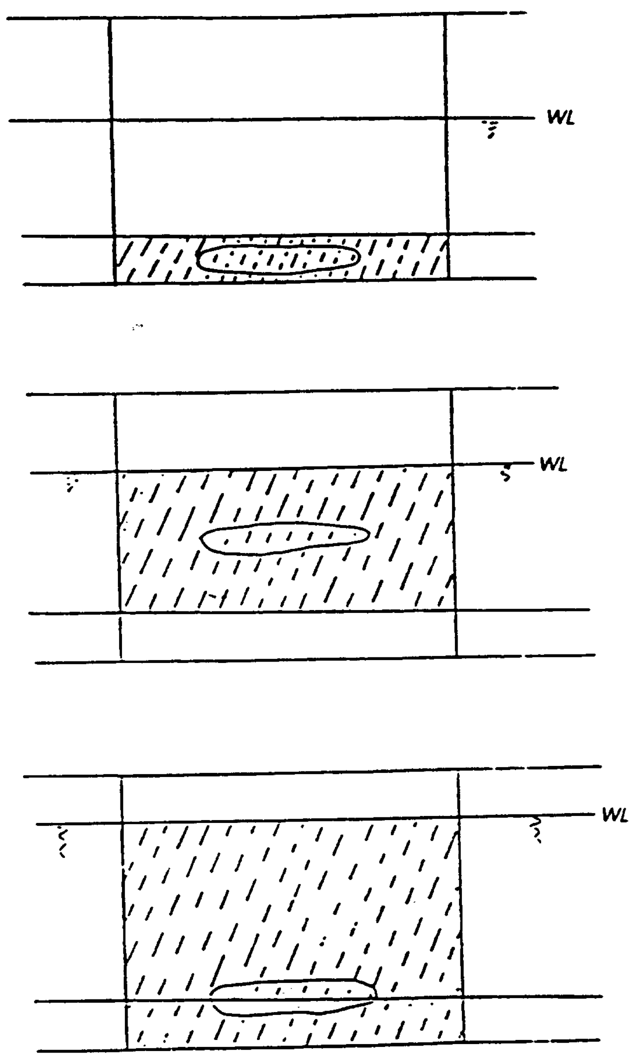

Figure 3

Some examples for dealing with other cases of horizontal subdivision are given in appendix 1.

2.2 Consideration of horizontal subdivision above a waterline

In the case where the ship has a horizontal subdivision above a waterline, the vertical extent of damage may be limited to the depth of that horizontal subdivision. The probability of not damaging the horizontal subdivision is represented by the factor v_i, as calculated according to regulation 25-6.

This factor represents the assumed distribution function of the vertical extent of damage and varies from zero for subdivision at the level of the waterplane, linearly upwards to the value of one at the level conforming to the minimum bow height according to the 1966 Load Line Convention (see figure 4).

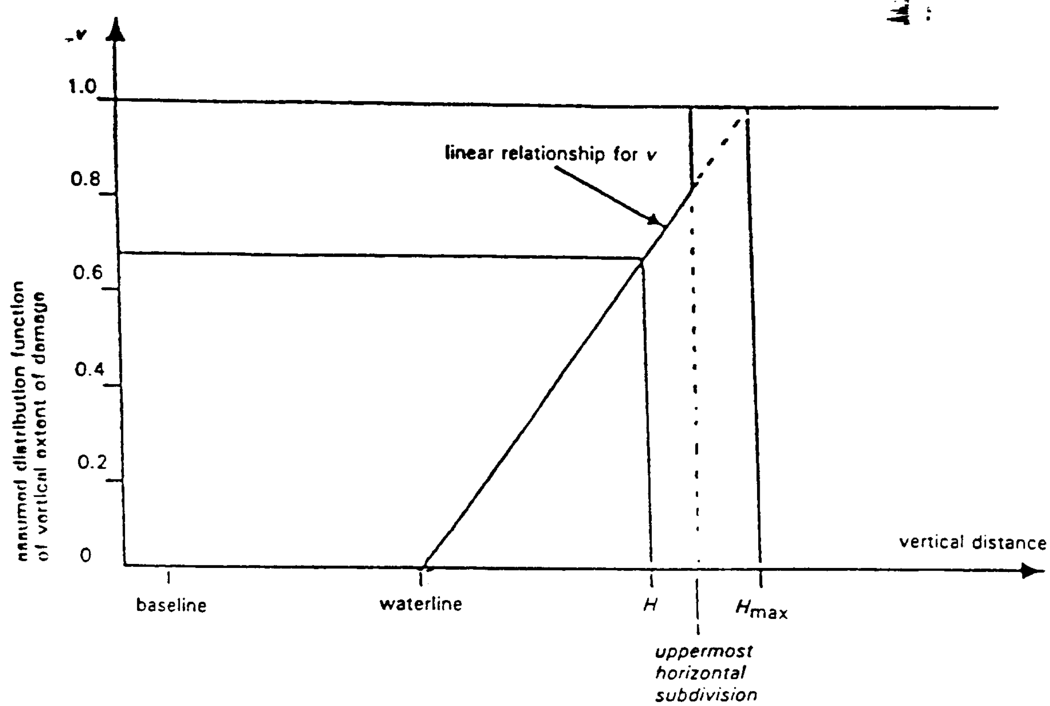

Figure 4

2.3 Consideration of damage penetration in addition to longitudinal damage location and extent

With the simplifying assumption that the damage is rectangular and with the vertical extent of damage according to 2.2, the damage can be described by the damage location x, the damage length y and the damage penetration z (see figure 5). These variables can be represented in a three-dimensional co-ordinate system, as shown in figure 6. Each point in the prism, with triangular base, represents a damage.

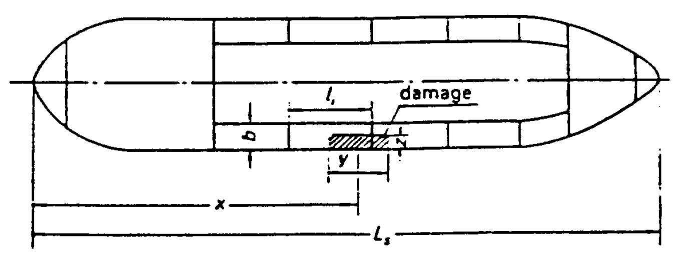

Figure 5

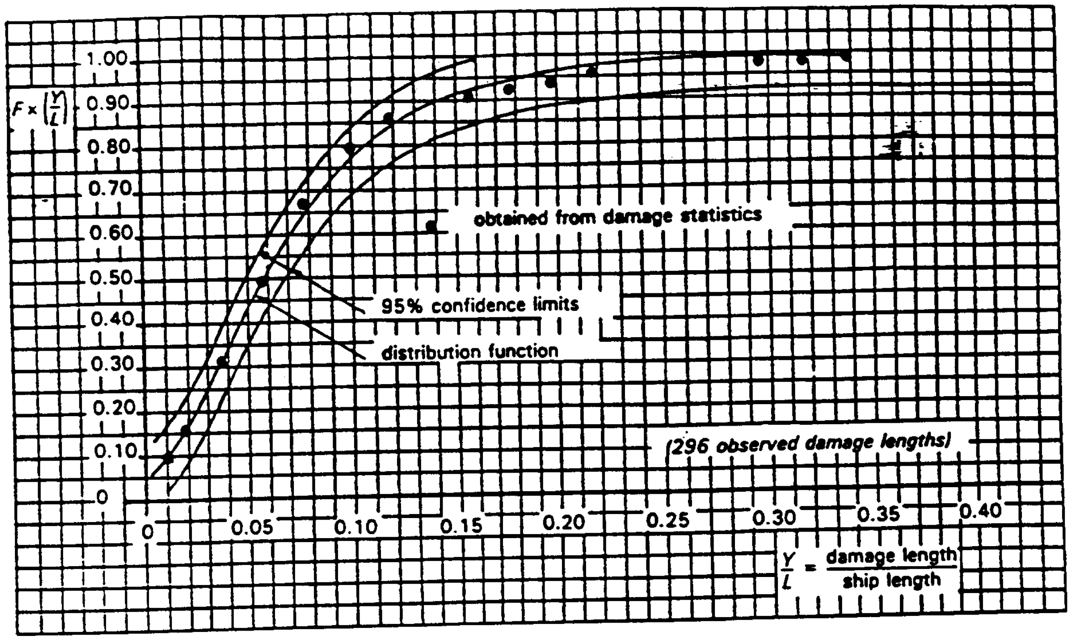

Figure 7 - *Distribution function of nondimensional damage length*

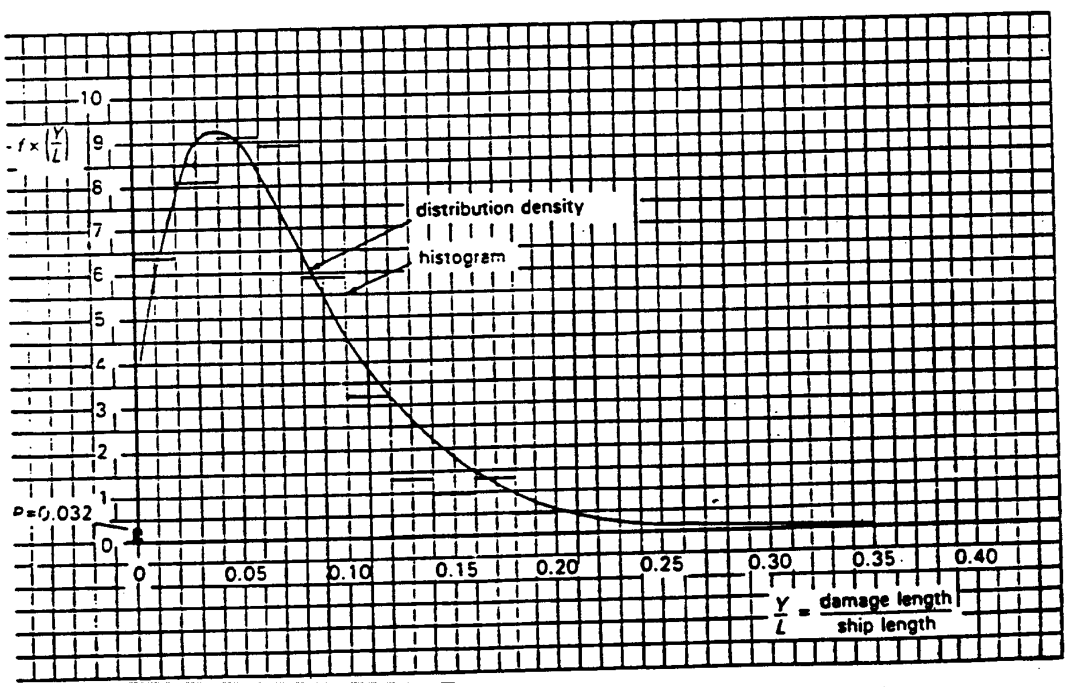

Figure 8 - *Distribution density of nondimensional damage length*

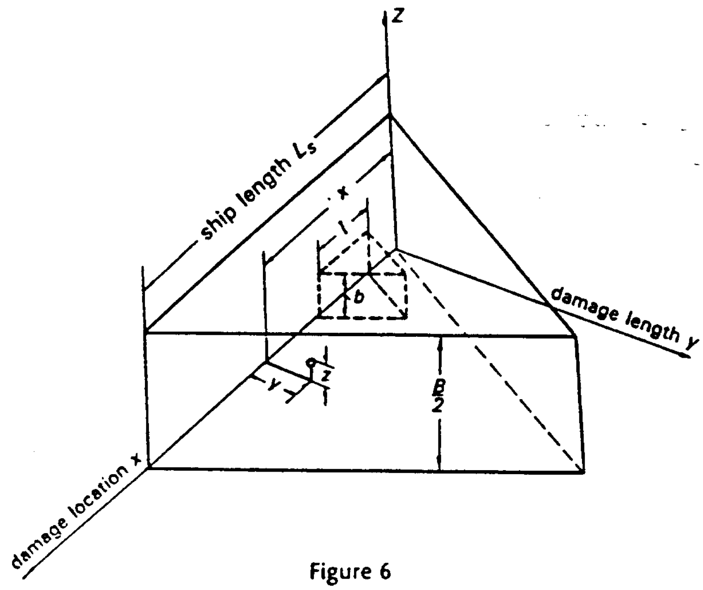

Figure 6

All damages which open a side compartment correspond to the points of a smaller prism with height b equal to the distance of the longitudinal bulkhead from the ship's side, which is erected above a triangle with the base l_i equal to the length of the side compartment under consideration. It is not difficult to identify in figure 5 the volumes which correspond to such damage which flood other parts of the ship bounded by transverse and longitudinal watertight structural subdivisions.

Damage location x, damage length y and damage penetration z are random variables. The distribution density $f(x,y,z)$ can be derived from damage statistics. This distribution density can be illustrated by assuming it to be a density which varies from point to point of the volume shown in figure 6. The "weight" of the total volume is one and represents the probability that there is a damage (which is assumed to be certain). The "weight" of a partial volume (representing the flooding of certain spaces) represents the probability that the spaces under consideration are opened.

The probability that a side compartment is opened can be expressed as $p_i r$, where p_i is to be calculated according to regulation 25-5.1 and r according to regulation 25-5.2. The probability that a centre compartment (extending at least to the ship's centreline) is opened, in addition to the adjacent side compartment, can be expressed as $p_i(1-r)$.

Some examples for the calculation of the probability that side or side plus centre spaces are opened are given in appendix 2.

Again, it must be stated that the probability calculated on the basis of the simplifying assumptions mentioned above is not exact. Nevertheless, it gives a comparative measure of how the probability of opening spaces depends on transverse and longitudinal structural subdivisions, and thus takes account of the most essential influences, whilst neglecting secondary effects. Neglecting the random variation of longitudinal and transverse damage extent would be a much greater error than that which is caused by neglecting these secondary effects.

3 DAMAGE STATISTICS

3.1 Source of data

The following considerations are based on the information contained in various IMO documents. They summarize casualty data reported to IMO on 811 damage cards. There are 296 cases of rammed ships which contain information on each of the following characteristics:

Ship length - L
Ship breadth - B
Damage location - x
Damage length - y
Damage penetration - z

In order to omit inconsistencies in the results derived from the data, which may be caused by the use of different samples, the following investigations have been based only on the aforementioned 296 cases. However, further investigations have been made using, in addition, the information given for other cases. Despite the random scatter, which is to be expected because of the use of different samples composed at random, they lead to the same conclusion.

For the investigation of the dependency of damage length on the year of collision, a different sample was used comprising 209 cases in which L, y and year of collision were given.

3.2 General consideration of damage extent

It is clear that the principal factors affecting damage extent are:

.1 structural characteristics of the rammed ship;
.2 structural characteristics of the ramming ship;
.3 mass of the rammed ship at time of collision;
.4 mass of the ramming ship at time of collision;
.5 speed of the rammed ship at time of collision;
.6 speed of the ramming ship at time of collision;
.7 relative course angle between rammed and ramming ship;
.8 location of damage relative to the ship's length.

From the point of view of the rammed ship only item .1 is pre-determined; all other items are random. An investigation of the damage length of ships with different numbers of decks has shown that there is no significant influence. This does not prove that there is no influence. It is, however, valid to conclude that the influence of structural characteristics is relatively small. It therefore seems justifiable to neglect this influence.

The mass of the rammed ship depends on its size and its loading condition. The influence of the latter is small and therefore for the sake of simplicity it has been neglected. To account for the size of the rammed ship, damage length has been related to the ship length and damage penetration to the ship breadth.

The following will show that the damage length does not depend significantly on the place at which it occurs in the ship's length. From this it is concluded that the damage extent does not depend on the location of the damage, except at the ends of the ship where damage length is bounded according to the definition of damage location as the centre of the damage.

Some comments on the mass of the ramming ship are given below.

3.3 Distribution of damage length

Preliminary investigations have led to the conclusion that the distribution of the ratio damage length to ship length y/L is more or less independent of the ship length. A proof will be given below. As a consequence, y/L can be taken as independent of L.

From theoretical considerations (using the central limit theorem) it follows that $y/L + \epsilon_y$ (where ϵ_y is constant) is approximately log-normally distributed. This is confirmed by figures 7 and 8, in which good agreement is shown between the log-normal distribution function and distribution density on the one hand and the corresponding results of the damage statistics on the other.

.2 ships where the side shell has been significantly strengthened by the provision of a *double skin* where it may be agreed to use enhanced values of the reduction factor *r* (regulation 25-5.2). In such a case, supporting calculations indicating the superior energy-absorbing characteristics of the structural arrangement are to be provided;

.3 vessels of a multi-hull design, where the subdivision arrangements would need to be evaluated against the basic principles of the probabilistic method since the regulations have been written specifically for mono-hulls.

Regulation 25-2

Paragraph 1.2

This definition does not preclude loading the ship to deeper draughts permissible under other load line assignments such as tropical, timber, etc.

Paragraph 1.3

The light ship draught is the draught, assuming level trim, corresponding to the ship lightweight. Lightweight is the displacement of a ship in tonnes without cargo, fuel, lubricating oil, ballast water, fresh water and feed water in tanks, consumable stores, and passengers and crew and their effects.

The draught corresponding to the partial load line is given by the formula:

$$d_p = d_{ls} + 0.6\,(d_l - d_{ls})$$

where:

d_p = draught corresponding to the partial load line (m);
d_l = draught corresponding to the deepest subdivision load line (m)
d_{ls} = light ship draught (m).

Paragraph 2.1

The definition of L_s according to paragraph 2.1 of regulation 25-2 is illustrated in figure 21.

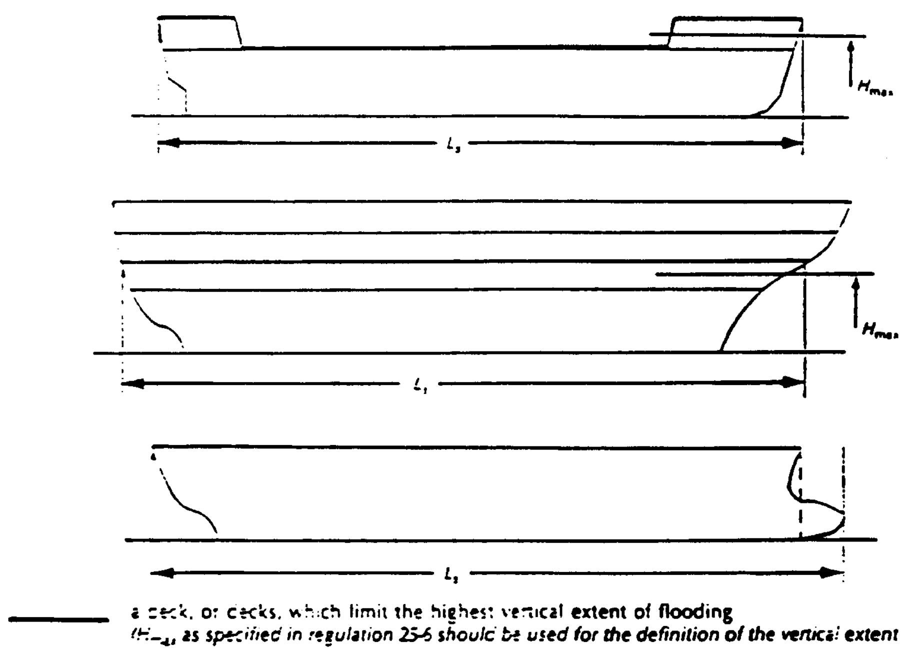

Figure 21 - *Illustration of the definition of L_s according to paragraph 2.1 of regulation 25-2*

Figure 9 shows the regression of y/L on L for $L \leq 200$ m (five damages relate to ships with $L > 200$ m). The regression line has a small negative slope which proved to be insignificant, and may be caused by samples taken at random. There might be a small dependence of y/L on the ship length, but it is so small that it cannot be derived from the given sample. It is therefore certainly no significant error to assume y/L to be independent of ship size for $L \leq 200$ m.

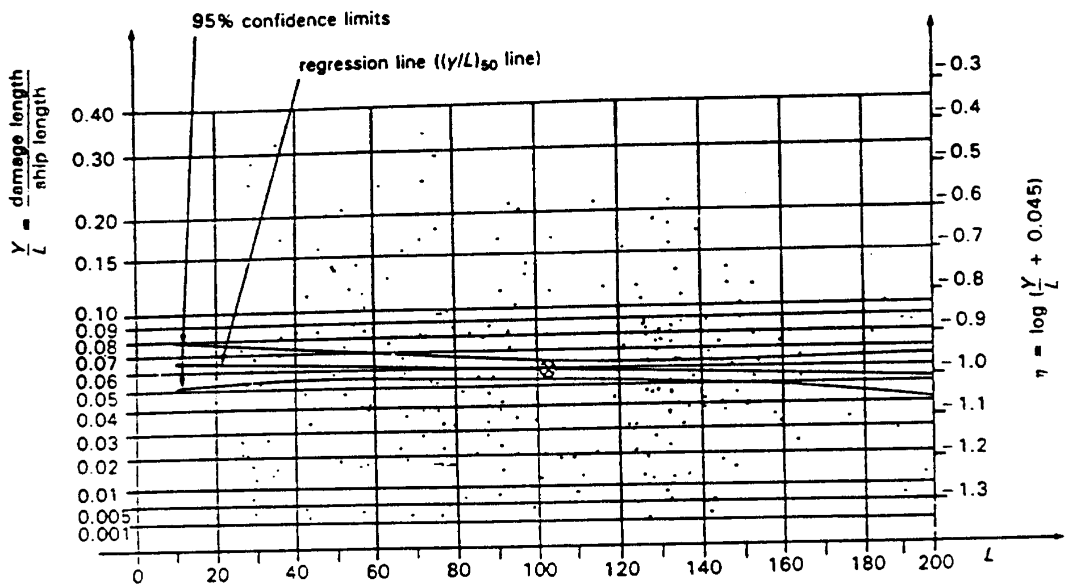

Figure 9 - *Regression of nondimensional damage length on ship length*

An explanation of this independence might be that small vessels are more likely to meet mainly small vessels and large vessels are more likely to meet mainly large vessels. However, this reasoning cannot be extended to very large vessels because of the small total number of such ships. Because of the very few damage cases concerning ships with $L > 200$ m, nothing can be said about the damage distribution of such ships. It seems reasonable to assume, as an approximation for ships with $L > 200$ m, that the median of the damage length is constant and equal to the median for $L = 200$ m. The latter equals $200 \times (y/L)_{50}$ where $(y/L)_{50}$ is the median of the nondimensional damage length for ships with $L = 200$ m.

The regression of the nondimensional damage length y/L on the nondimensional damage location is given in figure 10. This shows that there is no significant difference between the damage distributions in the forward and aft half of the ship, but simple geometric reasoning indicates that the damage length at the ends of the ship - forward as well as aft - is limited to smaller values than in the central part of the ship. Therefore the log-normal distribution found for all values for y/L - independent of damage location - is the marginal distribution. The corresponding conditional distribution of y/L, on the condition that the damage location is given, does not need to be considered as for the practical application an approximation will be used, which allows establishment of a very simple relationship between the conditional and marginal damage length distribution.

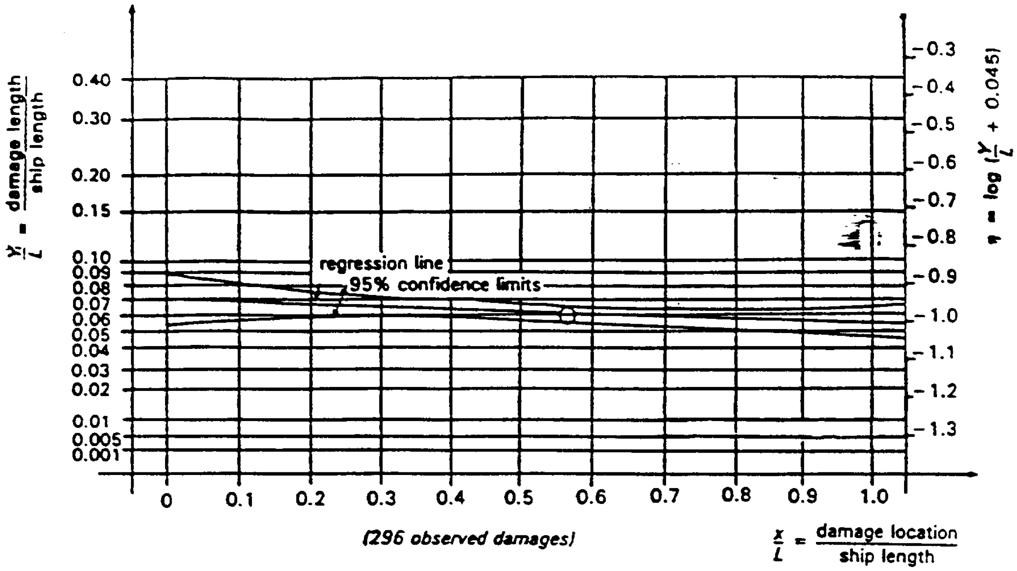

Figure 10 - *Regression of nondimensional damage length on nondimensional damage location*

3.4 Dependence of damage length on year of collision

The fact that the speed and size of ships has tended to increase during recent years suggests that the average size of damage in cases of collision is also growing. In order to investigate this, a regression analysis of the logarithm of the nondimensional damage length on the year of collision has been made. The result is shown in figure 11. This figure shows a significant positive slope of the regression line, which proves that, on average, the damage length increases with year of collision.

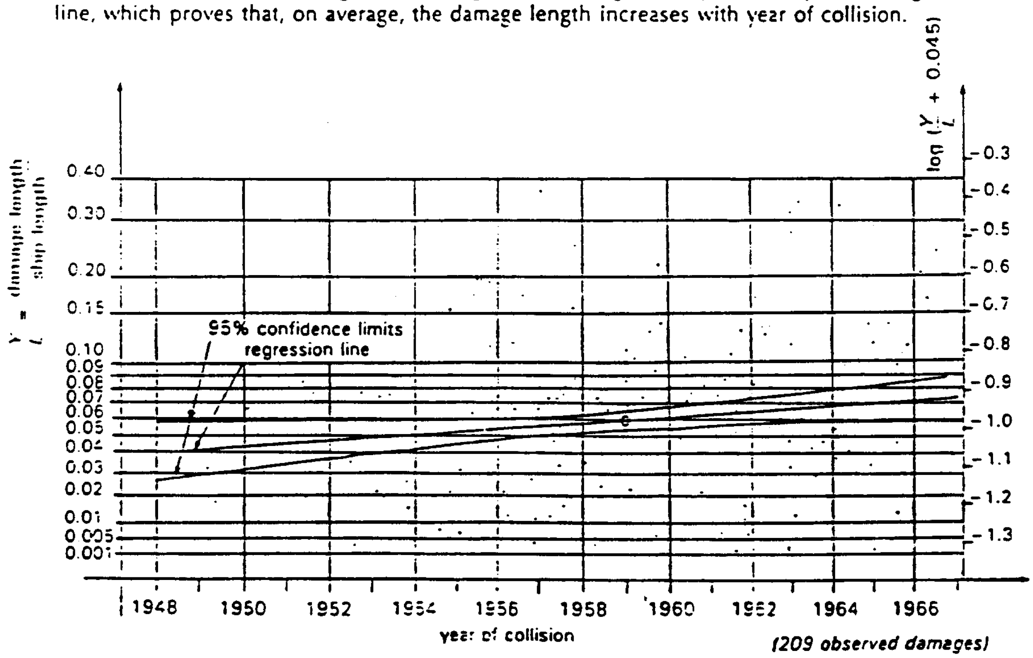

Figure 11 - *Regression of nondimensional damage length depending on year of collision*

It therefore seems prudent not to use the distribution which results from all damage data independent of the year of collision. Assuming that the variance about the regression line is constant, it is possible to derive from the regression analysis the distribution function of nondimensional damage length for any arbitrarily chosen year; such a function is determined by the mean (which is given by the regression line) and the variance about the regression line of the logarithm of $y/L + \epsilon_y$. Some samples are given in figures 12 and 13.

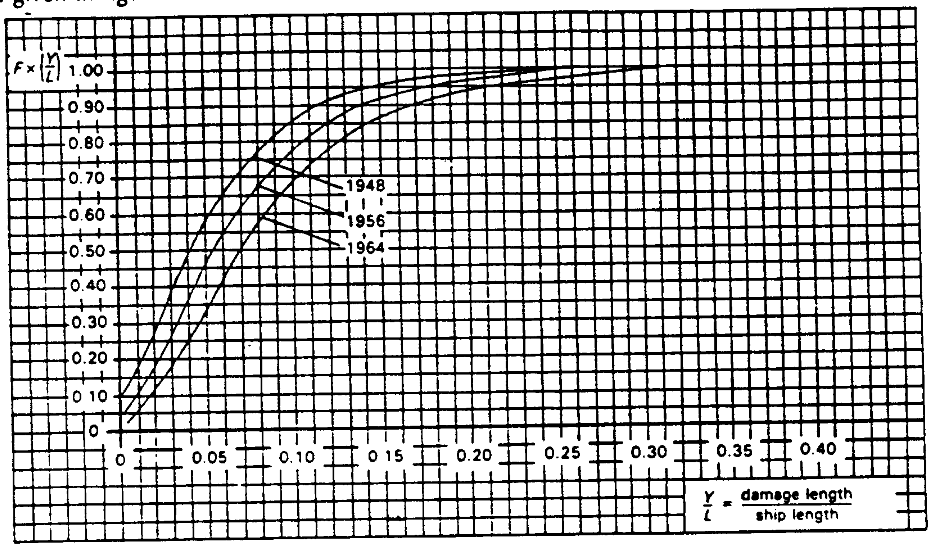

Figure 12 - *Distribution function of nondimensional damage length for respective year of collision*

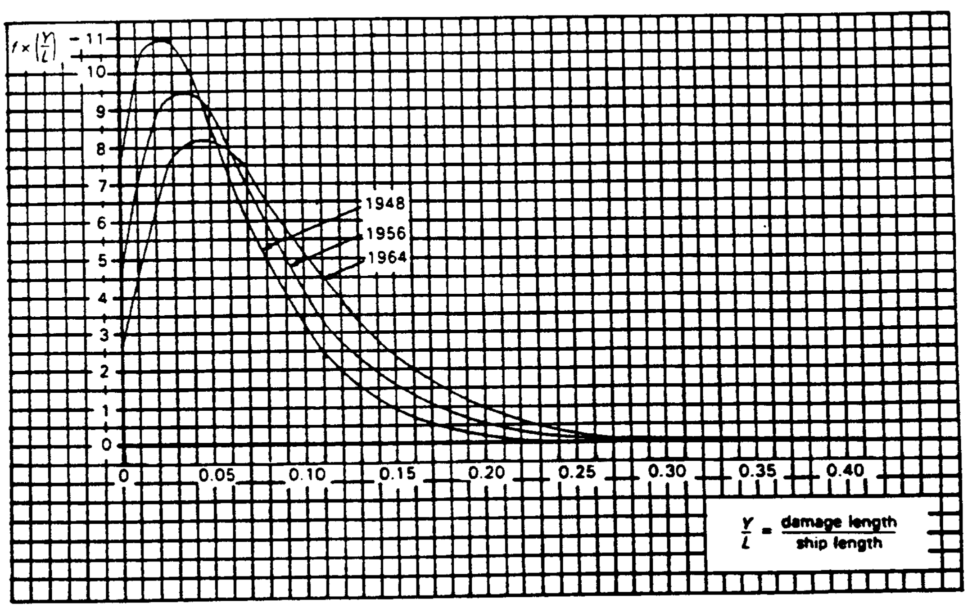

Figure 13 - *Distribution density of nondimensional damage length for respective year of collision*